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PHYSICAL PERFORMANCE AND CARBOHYDRATE CONSUMPTION IN CF COMMANDOS DURING A 5-DAY FIELD TRIAL

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This study evaluated the capacity of military personnel to perform maximal exercise before and after 5 days of sustained physical activity. An additional goal was to evaluate whether a carbohydrate supplement to the regular field rations would reduce the extent of any performance impairments. Subjects (Ss) were 29 male volunteers from the CF Airobrne Regiment. They were allowed 3-5 h sleep each 24h and 45 min per meal, but were otherwise continuously occupied with physically demanding missions in a field environment. Mean 24h energy expenditure in the field was estimated from continuous heart rate recordings and direct oxygen uptake measurements with field portable equipment, and ranged from 5500 to 6500 kcal. Nutritional energy consumption of regular field rations (Individual Meal Packets, IMP) was carefully monitored; regular IMPs, containing about 3600 kcal/day were distributed to half of the Ss, while the remaining Ss were free to eat IMPs but were also instructed to consume starch candies containing 240g carbohydrates each day. Performance tests administered 2 days before and at the end of the 5-day field trial included evaluations of maximal aerobic pwoer during cycle exercise, anaerobic power, muscular strength and endurance, rate of maximal force development and reaction time. M uscle and blood tissue samples were obtained before and after the trial to clarify the relative contribution of fat and carbohydrate energy stores to meeting the metabolic cost of the field tiral. The results demonstrated that the Ss were in a marked negative caloric balance by the end of the field trial. Skeletal muscle glycogen stores were markedly depleted. In association with these changes there were significant impairments at the end of the trial in maximal aerobic power, maximal dynamic strength, and anaerobic power of large muscle groups. These observations have direct implications for mission planning and physical performance expectations of military units involved in sustained operations.

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ABSTRACT

This study evaluated the capacity of military personnel to perform maximal exercise before and after 5 days of sustained physical activity. An additional goal was to evaluate whether a carbohydrate supplement to the regular field rations would reduce the extent of any performance impairments. Subjects (Ss) were 29 male volunteers from the Canadian Forces Airborne Regiment. They were allowed 4-5 h sleep each 24 h and 45 min per meal, but were otherwise continuously occupied with physically demanding missions in a field environment. Mean 24 h energy expenditure in the field was estimated from continuous HR recordings and direct oxygen uptake measurements with field portable equipment, and ranged from 5500 to 6500 kcal. Nutritional energy consumption of regular field rations (Individual Meal Packets, IMP) was carefully monitored; regular IMPs, containing about 3600 kcal/day were distributed to half of the Ss, while the remaining Ss were free to eat IMPs but were also instructed to consume starch candies containing 240 g carbohydrates (960 kcal) each day. Performance tests administered 2 days before and at the end of the 5-day field trial included evaluations of maximal aerobic power during cycle exercise, anaerobic power, muscular strength and endurance, rate of maximal force development and reaction time. Muscle and blood tissue samples were obtained before and after the trial to clarify the relative contribution of fat and carbohydrate energy stores to meeting the metabolic cost of the field trial. The results demonstrated that the Ss were in a marked negative caloric balance by the end of the field trial. Skeletal muscle glycogen stores were markedly depleted. In association with these changes there were significant impairments at the end of the trial in maximal aerobic power, maximal dynamic strength, and anaerobic power of large muscle groups. These observations have direct implications for mission planning and physical performance expectations of military units involved in sustained operations. (U)

INTRODUCTION

Combat personnel can frequently sustain periods of high energy expenditure, sometimes lasting for several days, which invariably exceed nutritional caloric (= energy) consumption (for review see Jacobs, 1987). The work of the skeletal muscles which are mainly responsible for the increased energy expenditure is fueled by a mixture of fats, proteins and carbohydrates stored within the body. An average sized male has approximately 81,000 kilocalories (kcal) of potential energy stored as fat, 35,900 kcal stored as protein, but only about 2,000 kcal stored as carbohydrates (Newsholme and Leech, 1983). It is very unlikely that either the fat or protein stores will become markedly depleted during such high levels of energy expenditure, which can exceed 10,000 kilocalories per day (Aakvaag et al, 1978; Rognum et al, 1986). In contrast, it is quite likely, and unfortunate, that depleted carbohydrate stores (in the form of glycogen) from the working musculature (and probably from the liver) will be associated with the negative caloric balance (Cedarmark, 1978; Jacobs et al., 1983).

There is a direct relationship between the concentration of glycogen in a muscle before it begins exercise and the time required to exhaust that muscle during relatively high intensity exercise (Bergström et al., 1967). Similarly, it has been repeatedly demonstrated that nutritional manipulations can be employed to avoid or delay the extreme glycogen depletion that is associated with performance impairments of the depleted musculature (for review see Conlee, 1987). To this end the ingestion of a relatively large proportion of total daily energy consumption in the form of carbohydrates has been shown to be beneficial to endurance exercise performance in both a laboratory and field setting (Bergström et al, 1967; Hermansen et al., 1981; Karlsson and Saltin, 1971). Therefore whether skeletal muscle is used for athletic endeavours or to carry out the missions of a commando unit, glycogen availability is probably crucial for the maintenance of physical performance.

In light of this information, the NDHQ Director General Land Doctrine Operations tasked the DCIEM Environmental Physiology Section to evaluate whether the caloric composition and quantity of field rations normally distributed to combat personnel are sufficient to meet the physical performance demands of a physically intensive field trial. The task sponsor organized a field trial at CFB Petawawa, from October 25th through November 1 1986, in order to carry out the tasking. This report describes the results and interpretation of the data collected during this trial.

The aims of this study were twofold:

(1) to evaluate whether voluntary nutritional carbohydrate consumption by CF infantry commandos during field trials is sufficient to maintain skeletal muscle glycogen concentrations at a level that will not compromise physical performance;

(2) to evaluate which physical fitness components, if any, were impaired after a five day physically demanding field trial.

METHODS

Subjects.

The subjects were 30 male soldiers, serving in the Canadian Forces Special Services Force, Airborne Regiment, 3 Commando Group. These personnel included one Warrant Officer and two Sergeants; the remainder were Troopers. One subject was unable to complete the trial because of foot blisters; his data have been excluded. After approval of the experimental protocol by the institutional Human Ethics Committee all subjects were briefed regarding the methods, procedures, associated risks and/or discomforts to be used during the trial. They were informed that they could refrain from participating in the invasive procedures without subsequent bias. Written informed consent was obtained. A copy of the written information distributed to subjects and the informed consent form is attached as Appendix A.

Testing Schedule.

Each subject underwent the same test battery before and after the five day field trial. The pre-trial testing took place over a two day period, 25-26

October. Evaluations of the following physical fitness components took place on the first day: dynamic muscular strength, explosive power, and muscular endurance of selected large muscle groups, and cardiovascular fitness. On the second day blood samples were obtained after which body composition measurements were made. Muscle tissue specimens were then taken after which the subjects made their final preparations before commencing the actual field exercise at 0001 h on 27 October. They returned from the field to the base for post trial testing at 2000 h on 31 October. Blood and muscle tissue samples were obtained immediately. The subjects then performed the fitness evaluation test battery in the same order in which the various tests were performed on the first day of the pre-trial testing. Appropriate rest intervals between tests were incorporated into the test battery to limit the effects of residual fatigue resulting from the tests. All testing was completed by 0500 h on 1 November.

Field Trial.

The activities comprising the field portion of this trial, codenamed Exercise Stalejoy, were designed to reflect the operational demands which the participating unit might meet if engaged in a real conflagration. There was thus a wide variety of activities demanding endurance fitness, such as forced marches (16 km) with full pack and weapons (>30 kg), as well as muscular strength and power, exemplified by the assault courses and casualty evacuations. The subjects were continually engaged in mission-oriented activities with the exception of the 4-5 hours of sleep each night (not including the night the trial began when there was no sleep), and the 30-45 minute breaks permitted for each meal. The trial was designed by the Commando Group Operations Officer. Each day's activities are described in Table 1.

Nutritional Manipulation and Analysis.

The subjects were divided into two platoons for the duration of the time in the field. A "shake-down" was conducted prior to departing for the field to ensure that the subjects did not have any foodstuffs other than those distributed to them. A 24-hour supply of field rations, containing 3 meals in the form of

Table 1. Field trial activities during Exercise Stalejoy.

Date	Time	Activity
25-26 Oct	0730-1600	Pre-trial testing
27 Oct	0001-0600	Prepare vehicle for IS ops
	0500-0600	Breakfast
	0600-0700	Battlefield 1st aid
	0700-0900	Navigate bayonet assault course
	0900-1000	Establish communications lines; Send/receive codes messages
	1000-1200	Navigate grenade assault course
	1200-1230	Lunch
	1230-1500	Conduct platoon quick attacks
	1500-1800	Stalking
	1800-1830	Dinner
	1830-2400	Navigate night map & compass course
28 Oct	0001-0400	Sleep period
	0400-0445	Breakfast
	0445-0700	Unload vehicles; Move stores through minefield
	0700-1000	House clearing drills
	1000-1045	Lunch
	1045-1600	Establish wire obstacle
	1600-1800	Establish platoon defensive position
	1800-1900	Dinner
	1900-2400	Continue establish defensive position
29 Oct	0001-0400	Continue establish defensive position
	0400-0800	Sleep period
	0800-0845	Breakfast
	1300-1400	Lunch
	1900-1930	Dinner
	0845-2400	Platoon ambush patrol
30 Oct	0001-0600	Continue platoon ambush patrol
	0600-0645	Breakfast
	0645-1000	16 km route march
	1000-1045	Lunch
	1045-1400	Correct indirect fire
	1400-1800	Establish NBC decontamination centre
	1800-1845	Dinner
	1845-2100	Probe minefield

	2100-2200	Establish communication lines; Send/receive coded messages
	2200-2400	Sleep period
31 Oct	0001-0200	Sleep continues
	0200-0600	16 km route march
	0600-0645	Breakfast
	0645-1115	Day navigation exercise
	1115-1200	Lunch
	1245-1400	Stalking
	1400-1500	Battlefield first aid
	1500-1600	Establish communication lines; Send/receive coded messages
	1600-1800	Navigate bayonet assault course
	1800-2000	Unload vehicles; Move stores through minefield
	2000	Return march to base for post trial testing

Individual Meal Packs (IMPs), was distributed to each soldier daily. Each IMP contained a main entrée in an airtight sealed foil pack which could be placed in boiling water to be heated prior to eating. Various condiments, snacks and dehydrated foods were also part of the IMPs. A detailed description of the IMPs can be found elsewhere (Director Food Services, 1982; Nutridata, 1986). Once the IMP was opened the subjects were not permitted to exchange any part with anyone. One platoon was always given only the IMPs (non-supplemented group; NoSupp). The second platoon (supplemented group; Supp) was also given these same IMPs plus a package of jellied candy strips; each package contained 12 strips totalling 240 g of carbohydrate. Both platoons were instructed to eat and drink "ad libitum" from their IMPs. The Supp platoon was instructed that in addition to whatever they chose to eat from the IMPs, it was mandatory to consume all 240 g of the carbohydrate jellies each day. On Day 5 in the field only 180 g of CHO were distributed since no food intake was permitted after 1200 h. Each day 30-60 minute breaks were allotted for each meal. At the end of each meal the uneaten portion, the empty packages, and all related food or packaging waste were collected in separate bags for each soldier. Each item was weighed and the amount consumed was calculated by difference from the known mean package weight. Nutrient intake for each soldier was calculated on a meal-by-meal basis using the CANDAT computer system (Bright-See et al., 1986). The nutrient data bank used by this computer program is the Canadian Nutrient File, prepared by Health and Welfare Canada. For some foods, which were not of common use, the nutrient composition was obtained directly from the manufacturer or, in the case of the main entrées and fruits, from biochemical and calorimetric analyses carried out by the Ontario Research Foundation (ORF) (Licht, 1984). ORF analysed the content of crude fat by Soxhlet extraction and by Monjonnier extraction. Protein was analysed using the micro-Kjeldahl method and carbohydrate was calculated by difference. Food energy was calculated using Atwater factors as well as directly using bomb calorimetry. For foods for which more than one estimate of energy content was available, the value obtained by bomb calorimetry was used when calculating the soldiers' energy consumption.

Evaluation of Energy Expenditure.

Energy expenditure during the trial was estimated from continuous recordings of heart rate from six subjects in the control group and six subjects in the carbohydrate supplemented group, matched for height and weight. Each of these subjects was fitted with a solid-state data logging system (Vitalog®) which automatically sampled and recorded heart rate once each minute throughout the trial from a bipolar lead. Although the data logger was able to record data for the duration of the five-day trial, they were temporarily removed from the subjects for a few hours after two days in order to dump the data and to ensure that they were functioning properly. The electrodes were changed every 24 h in order to maintain good skin contact and to check for a skin reaction to the tape which held the electrodes in place.

Each subject performed a step-wise, incremental exercise test to exhaustion before the field trial, during which simultaneous measurements of oxygen consumption and heart rate were recorded. The relationship between heart rate and oxygen consumption was calculated with linear regression for each subject (r^2 ranged from 0.90 to 0.99). Based on these equations the predicted daily oxygen consumption was calculated from the number of minutes each day that heart rate was within the following heart rate ranges: 51-80, 81-100, 101-120, 121-140, 141-160, and 161-180 beats/min. The average heart rate for each of these ranges (i.e. 65, 90, 110, 130, 150, and 170 beat/min, respectively) was converted into oxygen consumption using the regression equation referred to above, then multiplied by the number of minutes that heart rate was actually within each of the five ranges in order to yield a daily total of litres of oxygen consumed. For the subsequent calculation of caloric expenditure an RQ of 0.85 was assumed, which results in the yield of 4.875 kcal/litre of oxygen consumed.

In order to more accurately document the energy demand of some routine activities performed by these personnel, direct measurements of oxygen consumption were performed on individual subjects with a portable oxygen consumption measuring device (Oxylog®) during the following steady-state activities: 16 km open road marching with full pack, cross-country marching, and trench digging. A detailed description of this device and some of its limitations can be found elsewhere (Harrison et al., 1982; Louhevaara et al., 1985; Ilmarinen et al., 1986).

Test Battery.

Cardiovascular endurance was evaluated by direct measurement of peak oxygen consumption (peak VO2) during exercise on a mechanically braked cycle ergometer (Monark®) with a continuous incremental protocol. The pedalling frequency was 75 revolutions/min and power output was increased by 75 W/min until volitional termination or exhaustion. Expired gases were continuously directed into a metabolic cart (Alpha Technologies®) where the mean oxygen uptake was automatically calculated for each 30 s period.

Muscular strength of selected muscle groups was evaluated using an isokinetic dynamometer (Ariel Computerized Exerciser® (ACE) apparatus). Documentation of the reliability and validity of the ACE has been reported previously (Jacobs and Pope, 1986). This equipment was used to measure force or torque production during maximum voluntary isokinetic contractions. After a warm-up of the muscle group to be tested, three maximal contractions were performed. If the force measured during the third contraction was more than 10% greater than either of the other contractions, the procedure was repeated. The following exercises were performed:

(a) supine bench press with the lever-arm controlled to move isokinetically at both relatively slow (10 °/s) and fast (45 °/s) velocities (note: the angular velocities refer to the velocity of the ACE lever-arm, not the anatomical levers);
(b) standing squats (knee and hip extension) at the same velocities used for the bench press;
(c) biceps curls (elbow flexion) at the velocities described above as well as isometrically with the inner elbow angle at 90 degrees;
(d) sitting unilateral knee extension and flexion at relatively slow (30 °/s) and fast (200 °/s) velocities.

The peak force or torque measured for each exercise was recorded as the maximal strength for that particular exercise.

Upper body muscular endurance was evaluated by having the subjects perform 30 consecutive, maximum voluntary repetitions of the bench press exercise described above at an angular velocity of 25 °/s. This velocity of the dynamometer lever arm translates into an angular velocity of about 180 °/s at the elbow joint.

Muscular power and muscular endurance of the lower leg musculature was evaluated with the Wingate Anaerobic Test. The test consisted of pedalling at maximal frequency for 30 s against a resistance of 75 g/kg body weight. A mechanically braked cycle ergometer (Cardionics®) was used in which one pedal revolution caused a 6 m progress at the perimeter of the flywheel. For every 1/3 pedal revolution, an impulse was received by a pre-programmed calculator which printed out the average power output (in watts) for every 5 s period during the test. The calculated performance variables were the peak power which is the highest power output during any of the 5 s periods, the mean power generated during the 30 s, and a fatigue index calculated as the power output during the final 5 s expressed relative to peak power.

Muscle Biopsies and Blood Sampling.

In order to quantify changes in the concentration of glycogen a muscle tissue sample was obtained from the quadriceps femoris vastus lateralis muscle using the percutaneous needle biopsy technique (Bergström, 1962). Samples were taken 2-4 hours after the subjects had eaten their last uncontrolled meal on base, which was approximately 5 hours before commencing the field portion of this trial. The samples were taken again as soon as the subjects returned to the base at the conclusion of the field phase. All samples were taken using local anaesthesia (Xylocaine 10 mg/ml, mixed with 2% epinephrine). The biopsy incision was covered with Steri-Strips. Most of the subjects felt stiffness in the thigh for about 24 hours. This stiffness did not prevent them from carrying out any of the required tasks. Half of the tissue specimen was immediately frozen in liquid nitrogen and then kept on dry ice until stored in a -80 °C freezer. The tissue was freeze-dried and glycogen concentration was then assayed as glucose residues after hydrolysis in hydrochloric acid using enzymatic fluorometric methods (Karlsson, 1971). The remaining tissue was mounted in an embedding medium for subsequent histochemical analysis. Serial cross-sections of the muscle tissue were stained for calcium-activated myofibrillar ATPase activity after pre-incubation at a pH of 10.3 to enable the identification of fibres as either fast twitch or slow twitch (Guth and Samaha, 1970). Another section was stained for NADH (Novikoff et al., 1961) and this sample was used to calculate the mean cross-sectional area of the muscle fibres using computerized planimetry.

Venous blood samples were also obtained from a superficial forearm vein at the same times the biopsies were taken. These samples were processed for assays of the following: hematocrit (microhematocrit centrifuge), hemaglobin (Total Hemaoglobin assay, Sigma Chemical®), whole blood glucose (Yellow Springs Instruments® Model 23A Glucose Analyser), plasma free fatty acids (NEFA C assay, Wako), and glycerol (Boobis and Maughan, 1983). The change in plasma volume between the pre-trial and post-trial samples was calculated based on the hematocrit and hemaglobin values (Dill and Costill, 1974).

Body Composition.

In order to characterize the subjects standard methods were employed to carry out hydrostatic weighing of the subjects in a swimming pool (Bell and Cox, 1984); this was only done during the pre-trial measurements. Both before and after the field trial standardized procedures were used to measure height, weight and skinfold thicknesses at five different body sites (triceps, subscapular, suprailliac, abdomen, and thigh) (Behnke and Wilmore, 1974). The sum of these five skinfolds was compared before and after the trial as an index of fat loss.

Statistical Analyses.

The Biomedical Statistical software program (Dixon, 1983) was used for all statistical analyses. The significance of inter-group differences was evaluated with a two-factor analysis of variance (group, i.e. Supp/NoSupp x time, i.e. pre/post) with repeated measures on the time factor. A significant interaction of the main factors would indicate that there was a differentiated effect of the field trial on the two groups. If no main statistical effect of the dietary carbohydrate suppplement was observed then the data of the two groups were collapsed for an evaluation of the field portion of the trial on the dependent variables using a one-way repeated measures analysis of variance. Statistical significance was set at $p \leq 0.05$. Data are expressed as mean±SD unless otherwise indicated.

RESULTS

Subjects.

The subjects' age, height, weight, and body fat content were 23.6±3.2 y, 1.78±.06 m, 77.6±6.9 kg, and 12±3 %, respectively. It was determined from the histochemical analyis of the muscle biopsy that the muscle fibre type composition was 60±11% fast twitch (FT) fibres in the vastus lateralis muscle. The mean cross-sectional area of the muscle fibres was 5944±1800 μm^2. There was no difference between groups for any of the physical characteristics, peak VO_2, muscle fibre type composition nor fibre areas. These subjects can be classified as being very fit, as expected because of their regular training.

Muscle Glycogen.

The mean group values for the concentration of glycogen in the biopsies obtained from the leg musculature are depicted in Figure 1. After the trial muscle glycogen concentration had decreased significantly to 65% of the pre-trial value. The ANOVA also showed a significant interaction of time with group; further analysis demonstrated that the absolute decrease in glycogen was greater in Supp than in NoSupp (170±60 vs 122±65 mmol/kg, respectively).

Figure 1. Muscle glycogen concentration (mean±SD) in the vastus lateralis muscle of the carbohydrate supplemented (Supp) and non-supplemented (No Supp) groups. The Post value was significantly less than the Pre value, the change being significantly greater for Supp than NoSupp.

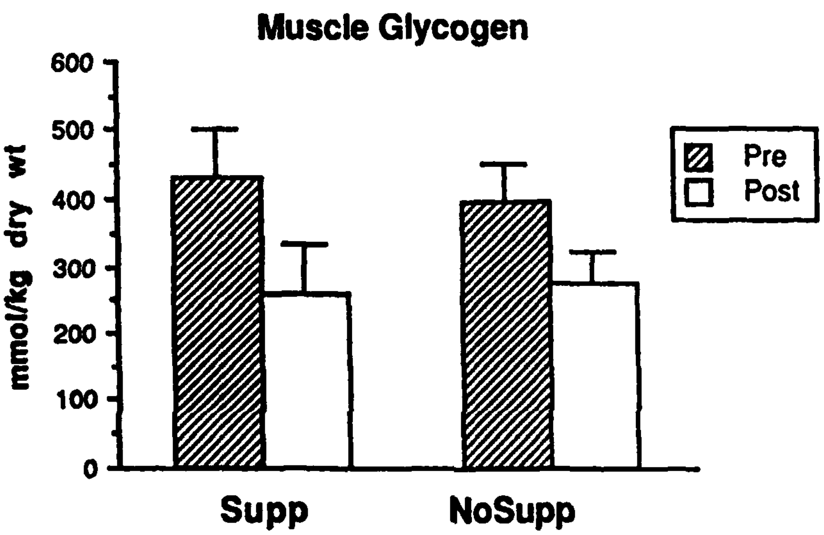
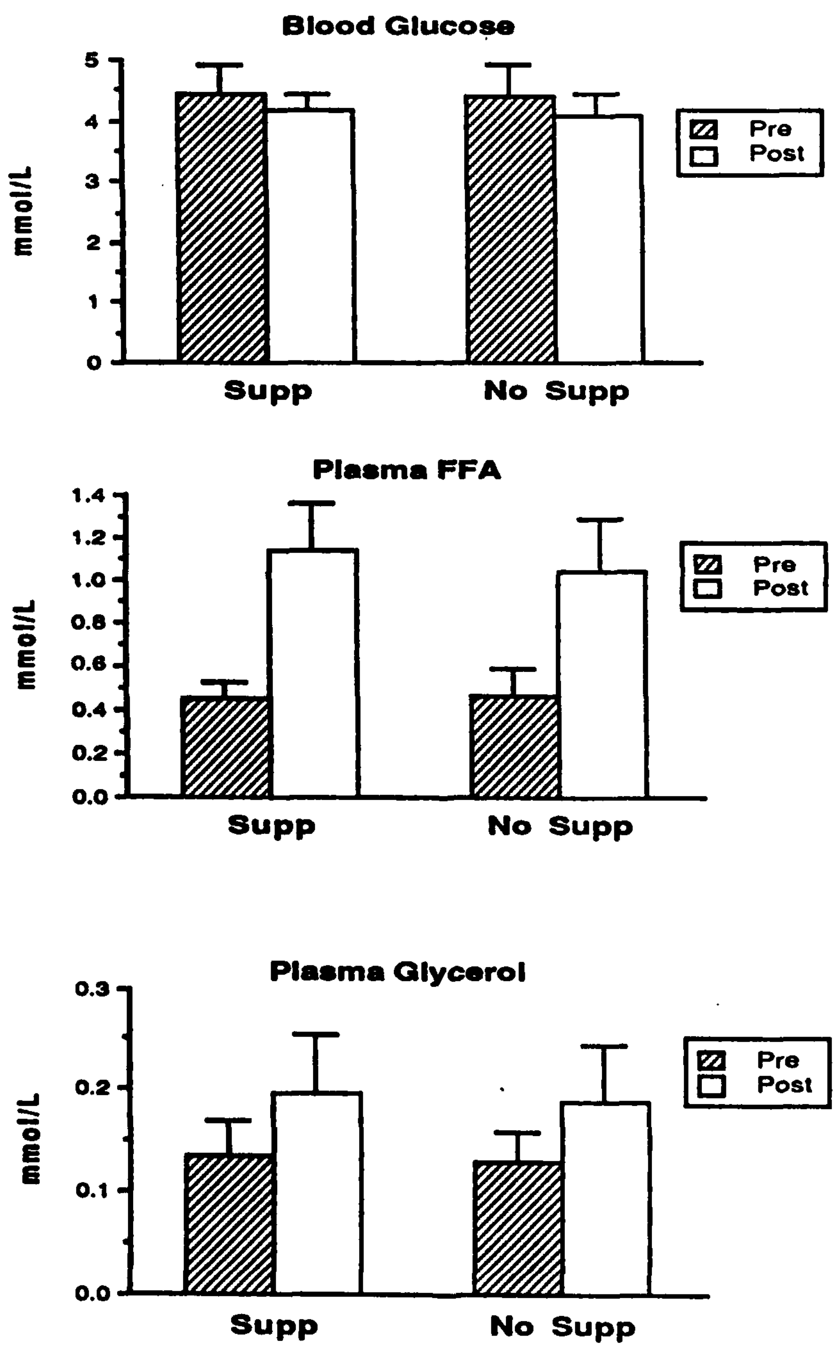


Figure 2. Blood glucose and plasma free fatty acids and glycerol concentrations before and after the field trial. All pre-post differences are significantly different, with no significant inter-group differences.



Blood Variables.

The pattern of change in the blood metabolites was similar in both groups. Blood glucose decreased slightly but significantly after the trial (from 4.38 to 4.13 mmol/L, $p=0.029$). Plasma FFA increased significantly (from 0.451 to 1.088 mmol/L, $p<0.001$) as did glycerol (from 0.133 to 0.191 mmol/L, $p<0.001$). These results are depicted graphically in Figure 2.

Plasma Volume.

The subjects apparently remained well hydrated throughout the trial as there was not a significant change in plasma volume. The pre and post trial values for hematocrit and hemaglobin concentrations were 45±2 vs. 43±2% and 156±10 vs 151±12 g/L, respectively. The calculated change in plasma volume was only -1.2%.

Body Composition.

There were significant decreases in body weight and all of the skinfold thicknesses, with the exception of the triceps which had the smallest thickness before the trial (Table 2). These data suggest that a significant proportion of the energy deficit described above was covered by release of lipids from the subcutaneous adipose tissue depots. Consistent with their significantly less average daily energy intake, the NoSupp group had greater decreases than Supp for both body weight and the sum of the five skinfolds.

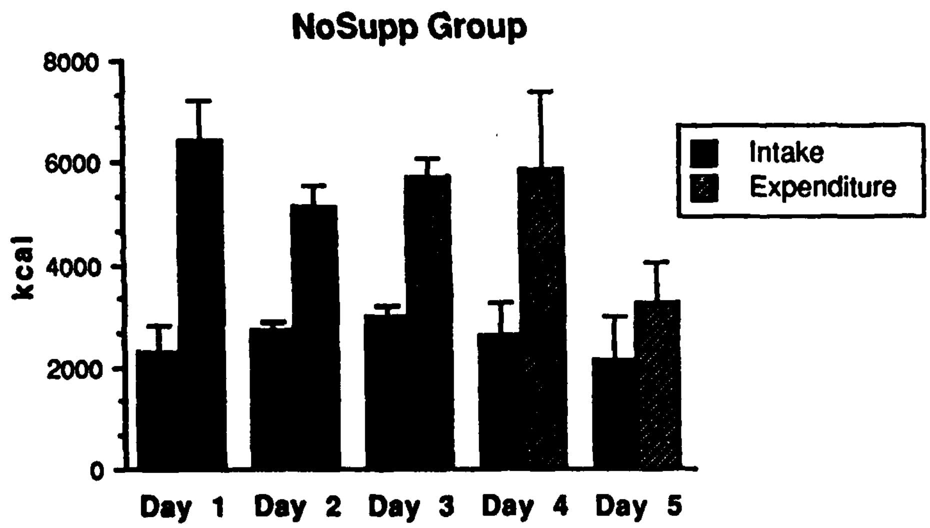
Energy Balance.

Since body weight was similar for both groups the caloric intake and expenditure have not been expressed per kg body weight. Figure 3 shows the mean energy intake and estimated energy expenditure for both groups on each day of the field trial. Table 3 shows the composition of the energy consumption. As expected, the Supp group had a significantly higher caloric consumption than NoSupp; this difference is not significant if the caloric value of the carbohydrate supplement is subtracted from the total energy consumption (Table 3). Thus the Supp group did not reduce their consumption of the regular IMPs to compensate for the ingestion of the supplement.

Table 2. Body weight and skin-folds before and after the field trial. The significance of the main statistical effect of the pre/post comparison and of any interactions with the grouping factor are indicated (*=p<0.05; **=p<0.01; ***p<0.001; ns=non-significant).

Variable		Supp	NoSupp	Main Effect of Pre vs Post	Pre/Post x Group Interaction
Weight	pre	77.2±7.0	78.0±6.6		
(kg)	post	76.1±7.3	76.1±6.4	***	*
Skinfolds (mm)					
Triceps	pre	8.20±2.86	8.22±2.71		
	post	8.09±2.74	7.93±2.63	ns	ns
Subscapular	pre	10.86±2.64	11.26±2.80		
	post	10.35±2.82	10.74±2.97	***	ns
Suprailliac	pre	15.49±7.02	16.41±5.34		
	post	13.56±6.11	13.62±5.15	***	ns
Abdomen	pre	12.48±5.78	13.26±4.09		
	post	11.69±5.45	12.09±4.04	***	ns
Thigh	pre	10.32±3.63	11.57±3.83		
	post	10.25±3.40	10.45±3.30	**	*
Sum of 5	pre	57.36±18.93	60.72±15.04		
	post	53.94±18.06	54.84±14.82	***	*

Figure 3. Mean energy intake and estimated energy expenditure on each day of the field trial.



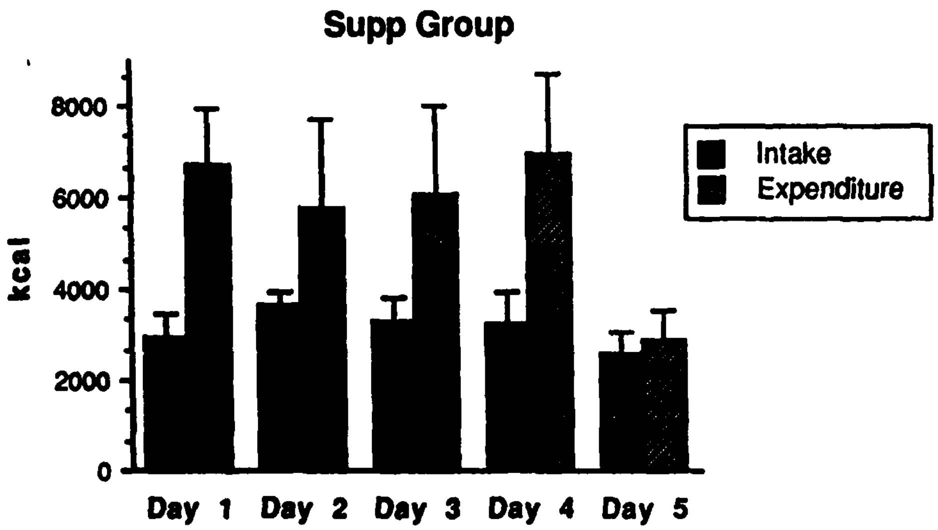


Table 3. Mean±SD daily energy intake and the absolute (in grams) and relative amounts of carbohydrate (CHO), fat and protein consumption during the five day field trial. * indicates significantly different from the NoSupp group ($p<0.001$).

Variable	Units	NoSupp	Supp
Energy	kcal	2571±303	3217±410* (IMPs + supplement)
			2305±410 (from IMPs alone)
CHO	grams	368±56	537±53*
	%	57±4	67±4*
Fat	grams	74±10	71±15
	%	26±4	20±3*
Protein	grams	84±13	81±18
	%	13±1	10±2*

A detailed listing of each subject's meal-by-meal quantitative and qualitative nutritional energy consumption is available elsewhere (Nutridata Consulting, 1986).

Both groups had similar values for the calculated daily energy expenditure, averaging over 6,000 kcal/24 hours (after extrapolating the Day 5 data to 24 hours). The average caloric deficit amounted to about 2,600 kcal/day which accumulated to about 13,000 kcal by the end of the trial. Since the subjects remained well hydrated throughout the trial (see plasma volume data) we assume that almost all of the 1.5 kg body weight loss was a function of fuel being oxidized to cover the energy deficit. Although admittedly a simplification, it is interesting that the oxidation of about 1.5 kg of fat would closely approximate the 13,000 kcal caloric deficit.

Table 4 shows the steady-state oxygen uptake predicted and/or directly measured during selected activities. These data demonstrate that the physical intensity of the tasks demanded of the subjects ranged greatly. Some of the tasks, such as the cross-country march and trench digging, elicited metabolic rates which were only 30-35% of peak VO2, a relatively light work intensity which can be maintained for several hours. Other tasks, such as the assault courses, demanded extremely high intensity work at 90% of peak VO2; such intensities can only be maintained for less than an hour before fatigue forces the musculature to either stop working or to reduce the intensity of the work.

Physical Performance.

Table 5 lists the mean values for the various peformance tests. The data for the two groups have been collapsed since there were no statistical main effects of group and no significant interactions of group with time. Almost all of the performance variables showed significant impairments during the post trial testing, with very few exceptions. The tests of muscular strength seemed to suffer somewhat greater impairments than did peak VO2, i.e. our index of aerobic fitness. When expressed relative to the pre-trial values the most impaired physical performance variables were related to leg strength; the post

Table 4. Metabolic rate during selected tasks. Using continuous heart rate recordings a predicted value was interpolated based on the individual subject's pre-established heart rate/oxygen uptake relationship. For some of the tasks the directly measured oxygen uptake for these same subjects is also shown.

Task	Predicted from heart rate		Directly measured		n
	ml/kg/min	% peak VO2	ml/kg/min	% peak VO_2	
Grenade assault course	49	90			
Bayonet assault course	48	89			
Unload vehicle	36	67			
10 km march w/pack	21	42	16	31	10
Trench dig	18	36	15	29	16
Cross-country march	17	35	18	35	10

Table 5. Physical performance test results before and after the field trial. * indicates a statistically significant difference p<0.05); ns indicates not significantly different. Values are expressed as mean ±SD.

Test		Units	Pre	Post	Difference
Aerobic					
Peak VO2		*ml/kg/min*	52±6	49±6	*
Peak heart rate		*beats/min*	189±7	178±9	*
Muscular strength					
Bench press	10 °/s	*kg*	198±47	180±46	*
	45 °/s	*kg*	117 ±20	113 ±33	ns
Biceps curls	0 °/s	*kg*	90 ±17	78 ±20	*
	10 °/s	*kg*	139 ±35	128 ±35	*
	45 °/s	kg	91 ±21	87 ±22	ns
Squats	10 °/s	*kg*	378 ±75	314 ±70	*
	45 °/s	*kg*	234 ±48	228 ±54	ns
Leg extension	30 °/s	*Nm*	176 ±27	158 ±30	*
	100 °/s	*Nm*	147 ±21	131 ±18	*
	200 °/s	*Nm*	106 ±12	92 ±11	*
Leg flexion	30 °/s	Nm	91±12	86±12	*
	100 °/s	Nm	82±11	77±9	*
	200 °/s	Nm	65±8	60±6	*
Muscular endurance					
Leg peak power		*W*	937±100	909±125	*
Leg mean power		*W*	698±71	652±83	*
Leg fatigue index		*%*	53±6	47±9	*
Upper body total work		*J*	2196±469	1968±420	*

trial values showed an impairment of 10-17%. Maximal force generation was tested at both slow and fast velocities; the former gives a better indicator of muscular strength while the latter yields information about the power producing cabilities of the musculature. It was mainly maximal strength that was affected since force generated during the relatively rapid muscle contractions was for the most part not significantly affected (e.g. bench press strength, biceps curls, and squats at 45 °/s). Explosive power as measured by the peak and mean power generation during the Wingate Test was also significantly impaired.

DISCUSSION

In light of the established relationship between muscle glycogen levels and exercise performance a main goal of the present study was to document the changes in glycogen in CF infantry commandos. Therefore the main finding was that marked muscle glycogen depletion is associated with the caloric deficit incurred during the combat activities in which Canadian Forces infantry commandos are likely to be engaged. In addition, a 45% increase in carbohydrate consumption above that normally consumed did not prevent pronounced glycogen depletion after 5 days of military field manoeuvers.

The only other reports of changes in muscle glycogen in infantry personnel engaged in a field trial are from Sweden (Cedarmark, 1978; Jacobs et al., 1983). In one of these studies (Jacobs et al., 1983) a similar design was used which involved distributing a supplemented ration to half of the subjects for 4.5 days in the field. Even with this supplemented ration, and a daily intake of 593±112 g of carbohydrate, muscle glycogen was decreased to 46% of the pre-trial levels, a somewhat greater decrease than was observed in the present study.

It is possible to deplete intramuscular glycogen stores almost totally with prolonged exercise (Hermansen et al, 1967) or a combination of exercise and low carbohydrate consumption over several days (Bergström et al., 1967). Thus, although the present trial was only 5 days in duration, it is probable that a more sustained duration of combat, which is quite feasible for such a commando group, would result in progressively greater glycogen depletion. It has been clearly shown that when exercise is performed on consecutive days, pre-exercise muscle glycogen levels become lower each day (Costill et al., 1971). Therefore the performance impairments associated with glycogen depletion would occur earlier on each successive day. Based on laboratory experiments we can expect that the glycogen depletion observed in the present subjects would be associated with a 30% decrease in endurance if the soldiers had been required to perform relatively high intensity tasks over a prolonged period of time. It is also probable that self-pacing, or the work intensity at which soldiers choose to work, would also be reduced by the decreased availability of glycogen in the exercising muscles (Saltin, 1972; Askew et al., 1987a).

The rate of repletion of muscle glycogen stores during rest is primarily a function of the amount of carbohydrates consumed. After exhaustive exercise glycogen stores can be almost completely restored to normal levels within 24 hours with the ingestion of 9 g of carbohydrate per kg body weight, which amounted to 70% of the total energy intake in male runners (Costill et al., 1981). In the present study the carbohydrate consumption of the Supp group was similar, 7 g/kg or 67% of total energy intake. There are two major differences, however, between the runners referred to above and our military subjects. Firstly, military personnel maintain their high energy expenditure levels during sustained operations for significantly longer than do athletes, in large part due to the shortened sleep time. Secondly, the energy consumption is usually significantly less and, even if it is "ad libitum", potential energy intake is limited to the distributed rations.

The sustained high energy expenditure levels confirm several earlier studies which reported estimated daily energy expenditure levels greater than 5,000 kcal for infantry commandos (Aakvaag et al., 1978; Rognum et al., 1986). The marked caloric deficit has also been reported previously and has been attributed to both the unusually high levels of caloric expenditure as well as to an inability or willingness to consume a significant proportion of the available rations (for review see Jacobs, 1987). For example, in the present study the daily IMPs distributed to the soldiers contained approximately 3,600 kcal, yet only about 71% were consumed "ad libitum". Such voluntary "anorexia" has been reported previously and is partially due to the combination of environmental and exertional stresses (Lee, 1940; Adolph, 1947; Jacobs et al., 1983; Szeto, 1986; Askew et al., 1987a; Roberts et al., 1987). Rations that are difficult or time-consuming to prepare, or food that is not particularly palatable, would also contribute to the caloric deficit. It was not, however, within the scope of this study to determine why a significant proportion of the calories available in the IMPs was not consumed, although such an investigation is probably warranted.

It is reasonable to question our estimations of energy expenditure, since they are indirect. Most of the reports which have evaluated daily energy expenditure levels in the field have relied on the procedures employed in the present study where recordings of heart rate are used to predict oxygen consumption. Such methodology is fraught with potential errors, particularly when light and moderate levels of exertion are involved, because of the many factors which can confound the heart rate/oxygen consumption relationship. Environmental factors such as temperature and emotional stress can cause heart rate to increase in a non-linear manner with regard to oxygen uptake. Unfortunately, until recently, a more reliable and valid technology for determining caloric expenditure in a field environment has not been available.

A non-invasive, well tolerated technique has recently become available which involves the ingestion of doubly labeled water (Schoeller and van Santen, 1982). In simple terms, samples of blood, urine, or saliva can be taken after a few days; the dilution of the isotopes in these fluids is proportional to the metabolic water produced by oxidation of fuel substrates. In the future this technique should greatly facilitate energy balance studies in the field because of its documented high degree of validity (Klein et al., 1984; Schoeller et al., 1986; Schoeller and Webb, 1984). With this technique, a recent publication reported daily caloric expenditures of over 5,000 kcal for Australian soldiers undergoing jungle warfare training (Forbes-Ewan et al., 1989). The training was carried out on a base and consisted of lectures, demonstrations, short periods of intense activity (bayonet fighting and obstacle courses) and longer periods of moderately hard work (10-18 km marches). When this report is considered in light of the longer activity periods and shorter sleep time in the present study, our estimates of caloric expenditure seem quite reasonable.

The second goal of this study was to quantify any impairments of relevant physical fitness components after the trial. Consistent with earlier reports describing the effects of physically demanding field trials (Murphy et al., 1984; Legg and Patton, 1987; Askew et al., 1987b) we found a 15% decrement in strength and muscular endurance. Such impairments indicate that either muscular fatigue would occur significantly earlier than normal or that the maximal force exerted by the musculature would have to be proportionally decreased in order to delay fatigue. In either event, such impairments translate into a greater time required for loading/unloading (e.g. supplies, ammunition) or carrying tasks (e.g. casualty evacuation, backpacking of specialized weapons/equipment). They may also translate into an impaired ability to carry out missions requiring explosive power, such as rapid attacks or hand-to-hand combat. The significance of this finding becomes all the more important considering the recent US Army report that muscular strength was more related to field performance of infantry than other fitness components (Daniels et al., 1984).

Although earlier research suggests that impairments of strength and muscular endurance may be related to muscle glycogen availability (Maughan and Poole, 1981; Jacobs et al., 1981), this issue is still not clear (Symons and Jacobs, 1989). The fact remains, however, that such impairments do occur in association with, but perhaps not because of, the musculature being depleted of glycogen.

The question arises then, as to whether the observed performance impairments in the present study can be directly attributed to the accumulated caloric deficit. In an extensive review, Grande (1986) recently concluded that in the presence of sufficient nutritional consumption to ensure adequate vitamin status and to avoid ketosis, dehydration and hypoglycemia, performance was satisfactory during conditions of moderate energy expenditure up to a weight loss of 10% of the control body weight. It should be emphasized, however, that the mean daily energy expenditure by the soldiers in the present study was much greater than in those reports reviewed by Grande.

In a more prolonged trial, a lightweight daily ration containing 2000 kcal was recently tested as the sole source of food for 30 consecutive days during a field trial with American Special Forces soldiers (Askew et al., 1987b). Although weight loss in these soldiers (6% of original body weight) was significantly greater than in the control group consuming normal rations (2% of body weight), the effect on physical performance was variable. Although some indices of muscular strength and endurance, and peak oxygen uptake were impaired to a greater extent in the energy restricted group, other performance tests suggested that the effects are similar to the impairments demonstrated by the control group consuming normal rations. Thus, in light of these earlier reports and the results of the present study, it is difficult to attribute the observed performance impairments to nutritional insufficiencies without further basic research.

CONCLUSIONS

There is a marked caloric deficit in CF infantry commandos that is very evident already after only a 5 day field trial. This deficit can be partially attributed to the sustained high levels of energy expenditure, which exceeded 5000 kcal/24 hours for all soldiers in the present investigation. It is also due to a voluntary reduction in caloric consumption, demonstrated by the observation that only 71% of the calories available in the distributed rations were ingested. Depletion of glycogen stores in the leg musculature was observed, indicating that significant impairments of the ability to perform prolonged exercise were already inevitable at the end of this trial. Muscular strength and muscular endurance were also impaired by about 15% at the end of the trial.

RECOMMENDATIONS

1. Assuming that it is unavoidable that a significant proportion of the distributed rations will not be consumed, than it would be prudent to amplify the existing IMPs used by infantry commandos. Consideration should be give to including sufficient carbohydrate content in the daily ration so that approximately 600 g of carbohydrate will be voluntarily consumed.

2. Acknowledge and plan for the ≥ 15% physical performance impairment that is evident after 5 days in the field.

3. DCIEM is presently collaborating with a research contractor in establishing a centre for our future use of the double-labelled water technique for more precise calculations of energy expenditure over several days. Assuming that the collaboration is successful, it is recommended that further tasking of DCIEM's Environmental Physiology Section be initiated by the Director Food Services to more accurately document the energy expenditure of various Canadian Forces units.

ACKNOWLEDGEMENTS

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INFORMATION FOR PARTICIPANTS IN EXERCISE STALE JOY

Date: September 29, 1986

Title: **Effects of dietary carbohydrate supplements on exercise performance and muscle glycogen after military field maneuvers.**

Principal Investigator: Dr. I. Jacobs, Environmental Physiology Section

BACKGROUND

The NDHQ Directorate of Land Doctrine Operations tasked the Environmental Physiology Section's Exercise Group to evaluate whether the caloric composition and quantity of field rations are sufficient to meet the physical performance demands of a physically intensive field trial involving Special Services Force (SSF) personnel. The task sponsor has organized a field trial to take place October 25 through November 2, 1986 at CFB Petawawa in order to carry out the tasking.

AIM

The aims of this study are twofold:

(i) in light of the impairment of exercise performance associated with glycogen depletion of skeletal muscle, a prime focus of the study will be to evaluate whether carbohydrate consumption is sufficient to maintain skeletal muscle glycogen concentrations at a level that will not compromise physical performance;

(ii) to evaluate which physical fitness components, if any, are impaired after a five day physically demanding field trial.

PROTOCOL

Subjects. They will be approximately 30 male, regular military personnel from the Airborne Regiment's SSF, 3 Commando Group. Their military status dictates that they must participate in the field trial, i.e. they are not volunteers. They will, however, be given the opportunity to volunteer for the two days of testing procedures which will both precede and follow the five day field portion of this study. On October 15, the principle investigator will travel to CFB Petawawa to brief the units involved as to the details, discomforts and risks associated with the experimental protocol; written informed consent will be obtained from those volunteering for the test procedures. All subjects will be less than 35 years of age, accustomed to regular high intensity physical exercise, and their participation will be approved by a SSF medical officer before being allowed to participate in the testing procedures.

Dietary Manipulations. Half of the subjects will be given a supplement to their normal rations. This supplement will consist of 200 grams of carbohydrate per day in the form of jelly-like candy strips (manufactured by Ganong and sold commercially). These strips are presently packed as standard CF survival rations. The subjects will be instructed to consume the supplement during the day *ad libitum* in addition to their normal rations. The food that is not consumed from the distributed Individual Meal Packets (IMPs) will be collected after each meal for calculation of each subject's caloric consumption.

Testing. Each subject will undergo the same test battery before and after the five day field trial. The tests will be performed on base at CFB Petawawa. The DCIEM Biosciences Division medical officer, Maj. M. Kavanagh, will be present for all testing. The test battery will be performed over a two day period as follows:

Day 1.

Muscle strength will be evaluated on a computerized strength evaluation apparatus during maximal voluntary dynamic contractions of large muscle groups during squats, biceps curls, knee extension and flexion, and bench press.

Lower body muscular endurance will be evaluated with the Wingate Anaerobic Test which involves 30 seconds of cycle exercise at maximal pedaling frequency against a resistance that is set relative to body weight.

Upper body muscular endurance will be evaluated by having the subjects perform 30 maximal isokinetic supine bench press repetitions.

Maximal aerobic power (VO_2max) will be evaluated during continuous cycle exercise with intensity increasing each minute until a pedaling frequency of 60 rpm cannot be maintained.

Endurance capacity will be evaluated as a function of the blood lactate concentration after six minutes of cycle exercise at 200 W, which is a submaximal intensity for these subjects; a drop of blood (25 μl) will be obtained from the finger tip after the exercise.

Day 2.

Body composition will be evaluated with underwater weighing, and measurement of body girths and skinfold thicknesses.

Muscle glycogen concentration will be determined on biopsies taken from the vastus lateralis muscle (thigh).

Venous blood samples will be taken from a superficial forearm vein to permit determination of hematocrit, free fatty acids, glycerol and glucose concentrations.

Note: Test days will be the reverse of that shown above when the battery is performed after the five day field trial.

POSSIBLE SIDE-EFFECTS AND HAZARDS

From the exercise tests. Exhaustive exercise has ben reported to induce heart attack in the general population very infrequently. That possibility is miniscule in the present study considering that the subjects will be less than 35 years of age, accustomed to performing exhaustive exercise on a regular basis as part of their normal military training, and will be screened by their unit's medical officer prior to participation. Emergency resuscitation equipment will be on hand at the test locale and the investigators are trained and certified in cardio-pulmonary resuscitation.

From the biopsies and blood samples. Possible side-effects are described in detail in the informed consent form for invasive procedures. Bruising and a feeling of stiffness in the punctured site is the only side-effect that has been reported in conjunction with similar experiments at DCIEM involving literally thousands of venous blood samples and over a thousand muscle biopsies taken by Dr. Jacobs. The blood samples will be taken with Vacutainers by Maj. M. Kavanagh and I. Schmegner. The biopsies will be taken by Maj. M. Kavanagh and Dr. I. Jacobs.

VOLUNTEER CONSENT

Title: Effects of dietary carbohydrate supplements on exercise performance after military field maneuvers.

Principle Investigator: Dr. I. Jacobs, Environmental Physiology Section

1. I hereby volunteer and agree to participate as a test subject in the DCIEM experiments involving the effects of dietary manipulations on exercise performance. I have been informed to my satisfaction of all details of the experimental protocol and the associated risks and possible discomforts. I realize that the experiment involves a two-day high intensity physical exercise test battery both before and after field trials. I am aware that the experimental techniques will require a minute puncture of the finger-tip from which less than 1 ml of blood will be sampled. I will be continuously monitored for my physiological well-being by a competent and knowledgeable physiologist. I understand that no experimental technique will be used requiring penetration into any body orifice or direct penetration through the skin without my signing an additional informed consent form.

2. This consent is voluntary and has been given under circumstances in which I can exercise free power of choice. I have been informed that I may, at any time, revoke my consent and withdraw from the experiment, without prejudice, and that the scientists or medical doctor associated with the experiment may terminate it any time, regardless of my wishes.

3. I understand that before I begin any test session I must inform the medical doctor of any changes to my medical status. This information will include any medications I have taken and any medical or dental care/treatment received since signing this consent.

Date_________________Signature of Volunteer___________________________

Age of Volunteer_______ SIN____

Print Name of Volunteer____

Full Mailing Address____

Telephone Number___________________________________

DCIEM Principle Investigator____

Medical Doctor____________________Witness

VOLUNTEER CONSENT FOR INVASIVE PROCEDURES

Title: Effects of dietary carbohydrate supplements on exercise performance after military field maneuvers.

Principle Investigator: Dr. I. Jacobs, Environmental Physiology Section

1. In conjunction with the experiments in which I am participating as a subject, I agree to allow two (2) percutaneous muscle biopsies to be performed on my thigh. I have been informed that the procedure involves the injection of a local anaesthetic into the skin and underlying tissues of the outside of the thigh, midway between knee and hip; a one quarter inch long incision is made through the skin and a special needle is then inserted to withdraw up to 80 mg of muscle tissue. I understand that some discomfort may be associated with a 'pressing' feeling on the thigh when the biopsy needle is inserted. I realize that some possible-side effects which have been experienced by other subjects include muscle stiffness or a 'charley horse' for up to 48 hours, loss of feeling in a small area of skin in the lower thigh, a bruise in the area of the biopsy, infection of the wound. The wound will be closed with surgical tape and no activity restrictions are required. I may exercise and train as usual immediately after the experiments. A small scar, less than 1/4 inch long, will gradually fade but may remain permanently visible.

2. I agree to a blood sample being obtained from a superficial forearm vein both before and after the field maneuvers. I understand that some possible side-effects which have been very infrequently experienced by other subjects include fainting, bruising and infection.

3. The principle investigator, Dr. I. Jacobs, has discussed with me all details of the procedures involved with the blood and muscle tissue sampling, and the possible physiological consequences of such sampling.

4. My consent is given voluntarily and under free power of choice. I have been informed that I may revoke my consent to these sampling procedures at any time.

Date________________Print Name and SIN of Volunteer____________________________

Signature of Volunteer______________________________________

Signature of Medical Doctor________________________________

Signature of Principle Investigator__________________________________

Signature of Witness____